

THREE-DIMENSIONAL CRANIOFACIAL SURFACE MEASUREMENT TECHNIQUES

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Abstract

Accurate and precise measurement of three-dimensional (3D) surface in terms of linear distance, curve surface distance, area occupied and angles between surfaces have become key criteria particularly in reconstruction of craniofacial appearance where the main purpose is to restore a distorted or damage facial area according to surgeons and patients requirements from aesthetic point of view. This paper describes several techniques used in 3D surface measurement using practical mathematical computation together with the usability requirements descriptions. These techniques are described in terms of its purposes of usage, implementation process and mathematical calculation. We summarized in the end that all the above discussed approaches are practically useful in 3D surface measurement.

1.0 INTRODUCTION

Craniofacial pre-operative planning and post-operative prediction applications are gaining more and more attention since the introduction of computer-aided devices in medical realm. This is due to that applications associated with this field are crucial for many tasks in diagnosis and treatment planning, as for example in the pre-operative and post-operative of craniofacial surgery. Currently, it is common practice in radiology to use 2D measurement tools for the definition of distance, diameters, arcs or angles in planar slices of radiological data. This, however, gives only rough estimation for spatial measurements such as the extent of a 3D object. In particular, the volume of 3D objects can only be estimated roughly. Therefore, tools are required that integrate measurements in 3D visualizations. The development of measurement tools to be used in the context of complex 3D visualization is difficult because the user has to be provided with enough depth cues to access the position and orientation of such a measurement tool. A simple transition of the existing line-based 2D measurement tools into 3D is not sufficient.

An important aspect of medical 3D visualization is that 3D visualizations are derived by the analysis of slices of radiological data. Therefore it is desirable to combine 3D views with 2D views of the original slices. For measurements tasks this implies that measurement point should be visible and modifiable within the slice data. While 3D views have the advantage of showing the overall relations, in 2D views each and every voxel of the original Computer Tomography (CT) or Magnetic Resonance Imaging (MRI) data may be selected precisely.

The interactive use of measurement tools is the most flexible approach; however, it requires certain effort from the users' part and might be inaccurate. Therefore, we carefully analyzed which interaction tasks are of primary importance in order to reduce the interaction effort. Most of the measurement facilities described in this paper are primarily used for craniofacial surgery planning. The involved mathematical computations for the techniques used are depicted in detail.

2.0 THREE-DIMENSIONAL SURFACE MEASUREMENT

2.1 Usability Requirements

The usability of measurement tools depends on a number of presentation parameters. Among them are font parameters (size, color) and line parameters (line width). Generally, the selection of presentation parameters is guided by the following four requirements:

- a) **Distinct assignment of measurement numbers to objects.** It should be clearly recognizable to which object or region a measurement refers.
- b) **Distinct assignment of measurement numbers to measurement tools.** If several measurements are included in visualization it is necessary that the affiliation of a number to a measurement tool is visualized unambiguously. The placement of numbers and the choice of presentation parameters such as color are important for this goal.
- c) **Flexibility.** Due to the large variety of the spatial relations to be analyzed and due to personal preferences it is important that the default values concerning font and line parameters as well as units of measurement tools are adjustable.
- d) **Precision.** Direct manipulation exhibits a lack of precision which is an essential drawback for measurement tasks. Therefore, additional facilities are required to overcome limited precision. Incremental transformations by means of arrow keys (two additional keys are used for 6 degrees of freedom (DOF)) interaction are provided to support the fine-grained modifications. Furthermore, transformations of measurement tools may be specified by numbers. The header information of medical data is employed to define its resolution (size of a mesh or voxel) and to guide the precision of measurement numbers.

2.2 Selection Surface Measurement Methods, Purposes and Usability

In this section, five useful surface measurement as well as volume approximation methods are determined and discussed here. They are: linear distance measurement, curve surface measurement, area measurement, angle measurement and volume computation.

2.2.1 Linear Distance Measurement

Purpose:

Linear distance measurements are employed to define distance between objects or diameters in linear form. Such measurements are crucial for craniofacial surgery planning, where it is used particularly in measurement of direct distance between two or more facial landmark points selected. For example, it is used to measure the distance between exocanthion (ex) left and right. Figure 1 show a linear distance measurement between exocanthion (ex) left and right.

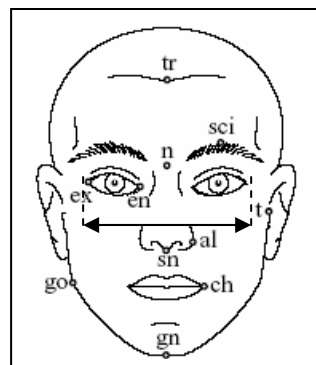


Figure 1: Linear distance measurement between exocanthion (ex) left and right.

Euclidean Distance:

Euclidean Distance is referred to straight line distance between two points. In a three-dimensional space plane with p_1 at (x_1, y_1, z_1) and p_2 at (x_2, y_2, z_2) , it is $\sqrt{((x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2)}$

$$\text{Euclidean distance, } e = \sqrt{((x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2)}$$

2.2.2 Curve Distance Measurement

Purpose:

Curve Distance Measurement is used to measure the distance along a particular curve surface in order to obtain an approximate value. In craniofacial surgery, it is applied to measure the curve distance between two or more interested facial anthropometry landmarks. Generally, a normal craniofacial landmarks measurement should fall within a certain range.

Curvilinear Measurements:

One of the logical variations of probe-based object measurements is to support interactive curve measurements. The intermediate approach involves summing the linear distances of segments between multiple-user defined surface points. A series of end-connected linear segments can be used to calculate a piecewise linear curve distance.

$$\text{Length}_{\text{curvilinear}} = s \sum_{i=1}^n \|p_i - p_{i-1}\|, \quad s = \frac{\text{world window dimensions}}{\text{view window dimensions in pixels}}$$

The piecewise linear method is appropriate for taking point to point cumulative approximations of object geometry dimensions.

As an interactive convenience, linear measurement segments can be placed automatically by projecting every probe pixel onto the object surface. The sum of the lengths of these automatically placed segments can give a more precise measure of a distance along the surface. There are, however, a number of caveats. The automatic placement of these line segments will not account for self-occluded areas for a particular view because the z-buffer does not contain complete surface information. Also, when viewing the object at a skewed angle, the automatically placed line segments may yield inappropriate measurements. To overcome these problems the probe segments can be “painted” onto the object surface and then viewed from another orientation to help the user determine if the measurement is appropriate.

2.2.3 Area Measurements

Purpose:

Area measurement is used in estimation of cross-sectional area of an object being viewed. In craniofacial surgery, area measurement is necessary when the surgeons need to know how much area to be operated for a hard tissue part especially for operation involved of skull.

Area Measurements:

Area measurements may be obtained by estimating the area between a given probe and its projected surface curve (Figure 2). Using the depth buffer this can be done by summing probe to surface depth difference $(z_{pi} - z_{si})$ over all points in the probe when the probe line is visible, and the adjusting for the view/world scaling.

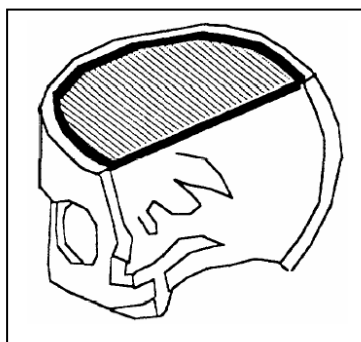


Figure 2: Area surface measurement.

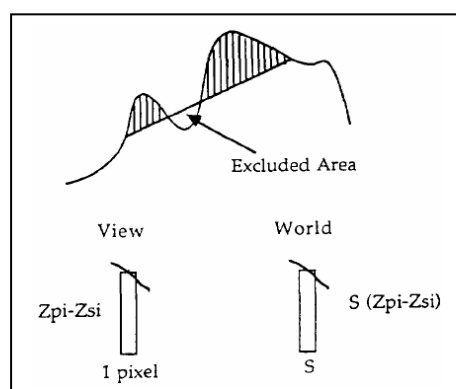


Figure 3: Area surface calculations.

As shown in Figure 3, the area is calculated by summing the areas under each pixel. Exclusion of areas between the probe and the viewer is accomplished by ignoring negative heights. This yields

$$\text{Area}_{\text{probe-curve}} = S^2 \sum_{i=1}^n \max(0, (z_{pi} - z_{si}))$$

This technique is subject to all of the same problems associated with automatic placement of measurement segments. As with the curvilinear measures, an alternative view of the measured area is needed in order for the user to understand exactly what is being measured. Such an alternative view is shown in Figure 2.

2.2.4 Angular Measurement

Purpose:

Angular measurements are carried out to define angles between anatomical or pathological structures. The angle at branching of vascular structures might be essential for vascular analysis, angles which describe orientation of bones are often important for the diagnosis and treatment planning in orthopaedics. In craniofacial surgery planning, angular measurements play an inevitable role. It is used by surgeons and doctors in determination of craniofacial appearance abnormalities and malfunctions. The measured angles indicated to what degree a lower jaw of a patient should be pushed back or pulled out or to how much a patient nasion part should be elongated. Figure 4, 5 and 6 show four different measurements conducted on craniofacial surface.

- i) Nasofrontal angle: It is formed by drawing a line tangent glabella through the nasion that will intersect a line drawn tangent to nasal dorsum.
- ii) Nasofacial angle: It is formed by drawing a vertical line tangent to forehead at the glabella and tangent to the chin at the pogonion so that a line drawn along the nasal dorsum intersects it.

- iii) Nasomental angle: It is formed by a line drawn through the nasal dorsum intersecting a line drawn from the nasal tip to soft tissue chin at the pogonion.
- iv) Mentocervical angle: A vertical line tangent to forehead passing at glabella and second line intersecting tangent to the chin at Pogonion.

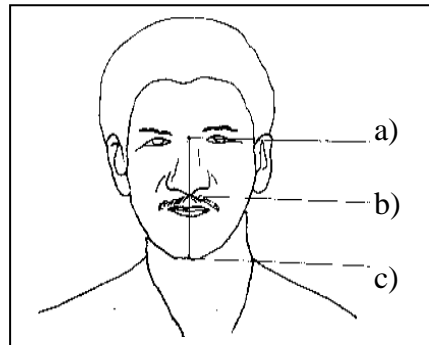


Figure 4: The land marks on the face a) Nasion (N), b) Subnasal (SN) and c) Menton (MN)

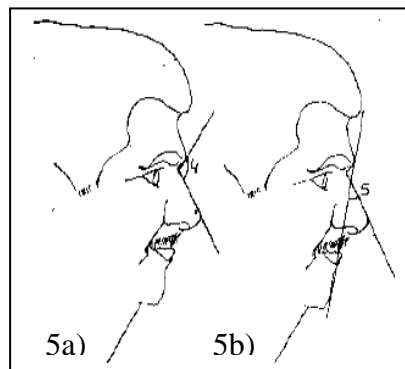


Figure 5: 5a) Nasofrontal angle and 5b) Nasofacial angle.

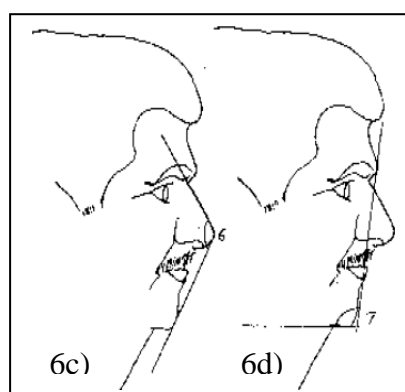


Figure 6: 6a) Nasoemental angle and 6b) Mentocervical angle.

Angular Measurements:

In angular measurements, three coordinates are required representing the apex of the angle and terminating the legs. In order to provide consistency across the measurement tools, the linear distance is used again for this purpose. So, the angular measurement tool thus consists of two linear distance lines. The apex of the leg is emphasized with a sphere which can be easily selected. It turned out that

without orientation aids it is often difficult to access the size of an angle. Therefore, semitransparent polygons are used as orientation aids when the angle is transformed.

Two semitransparent rectangles are created perpendicular to the legs of the angle. Two shapes have been designed to emphasize the plane in which the angle is located. First, the triangle formed by the three vertices of the angular measurement tool is displayed transparently. The use of a triangle as orientation aid is restricted to angles of less than 180 degrees (or would be ambiguous for angles larger than 180 degrees). Therefore, [3] have improved the initial design. With the new design, a portion of a circle is employed instead of the triangle to communicate the extent of the angle. The portion of the circle is smaller than the triangle. The portion is scaled such that the radius corresponds to the half length of the smaller leg.

Concerning the placement of the measurement number, two strategies have been used. First, the number has been integrated in one of the two distance lines which represent the legs. The second strategy is closer to the way angle are annotated in conventional technical drawings – the number is placed near the apex of the angle. The second strategy has the advantage that for larger angle the orientation is unambiguous.

3.0 CONCLUSION

Several techniques for three-dimensional surface measurement have been reviewed in this paper. These included: linear distance measurement, curve surface measurement, area measurement and angular measurement. Linear distance measurement is the most simple and direct method in measuring linear distance between two points. Curve surface measurement is used to get the approximate value between two or more surface points in curve form. Area surface measurement is applied by surgeons to determine the area involved when doing cross-sectional cutting or to measure the approximate area included. Angular measurement is conducted to determine the angle abnormality between craniofacial parts. All the above mentioned three-dimensional craniofacial surface measurement techniques are crucial and important in craniofacial surgery planning. This is due to the fact that safety is the first practice in operation besides to restore a pleasing facial appearance.

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